Root Cause Investigation by Furukawa

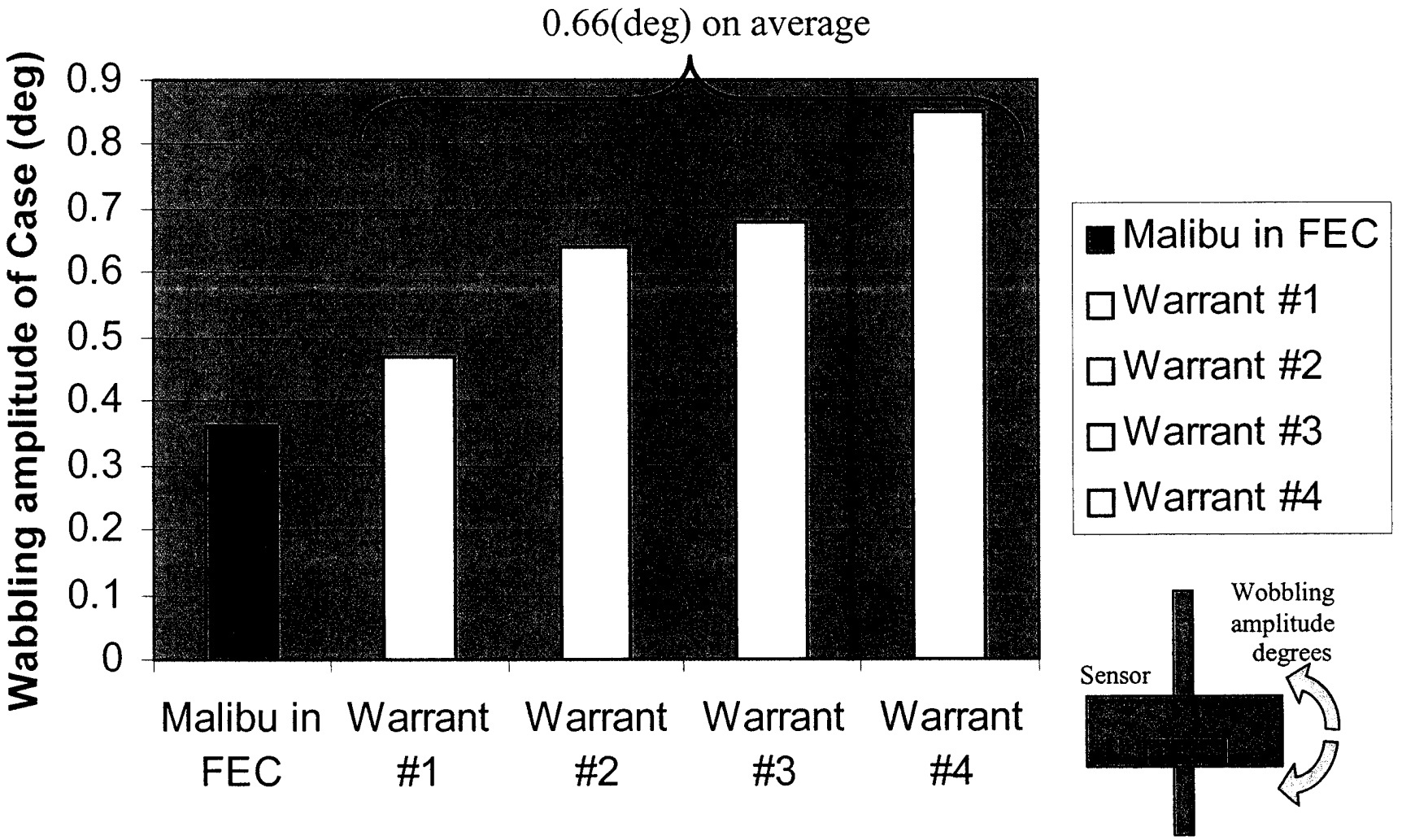
Wobbling of the sensor in EPS Column

13/May/2004 Furukawa Electric Co.,Ltd.

1. Analysis of Warranty returned sensors.

13/May/04 FEC

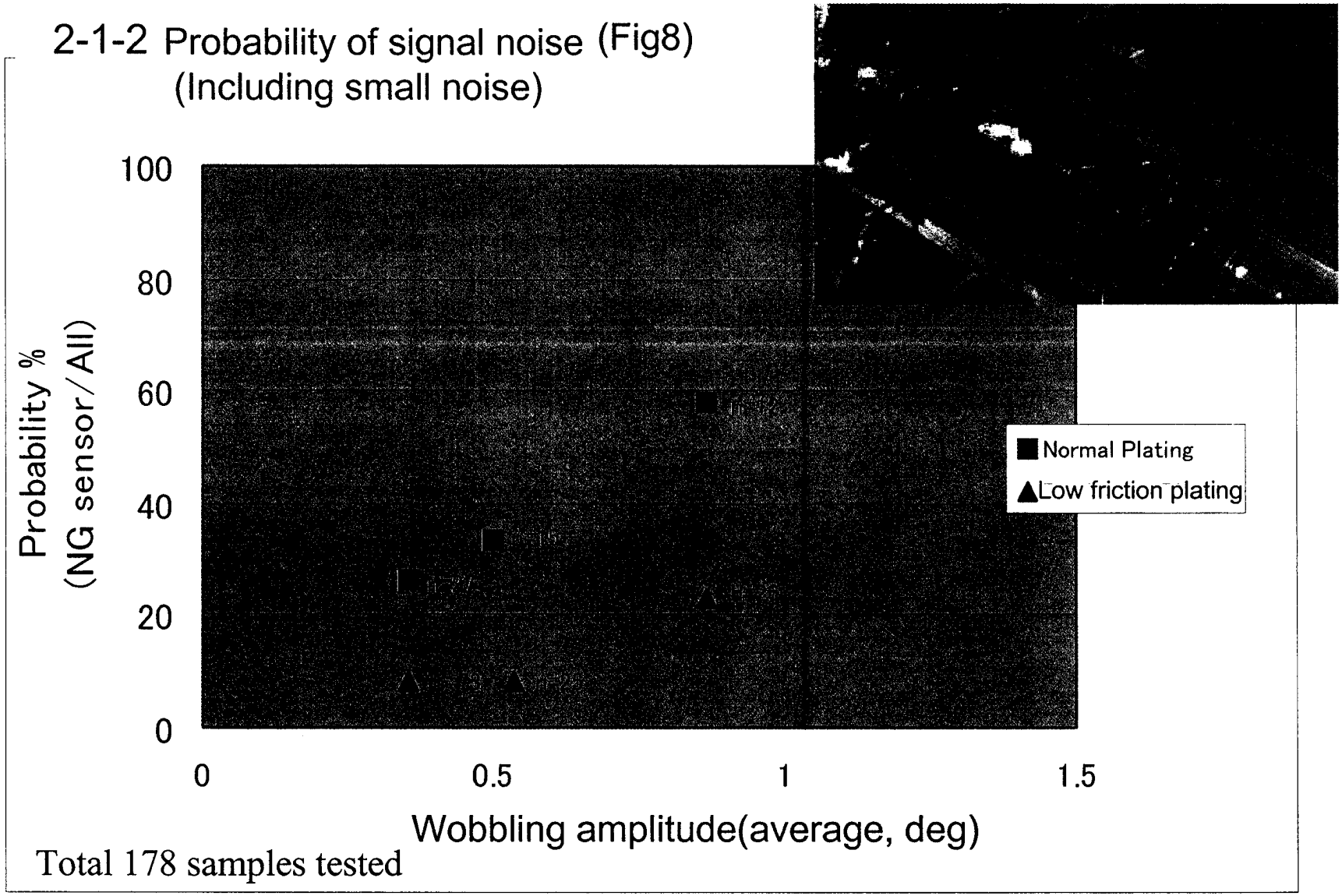
1-3 Wobbling amplitude of sensor in EPS column (Fig6)



Confidential

2. Signal noise duplication during sensor wobbling

13/May/04 FEC



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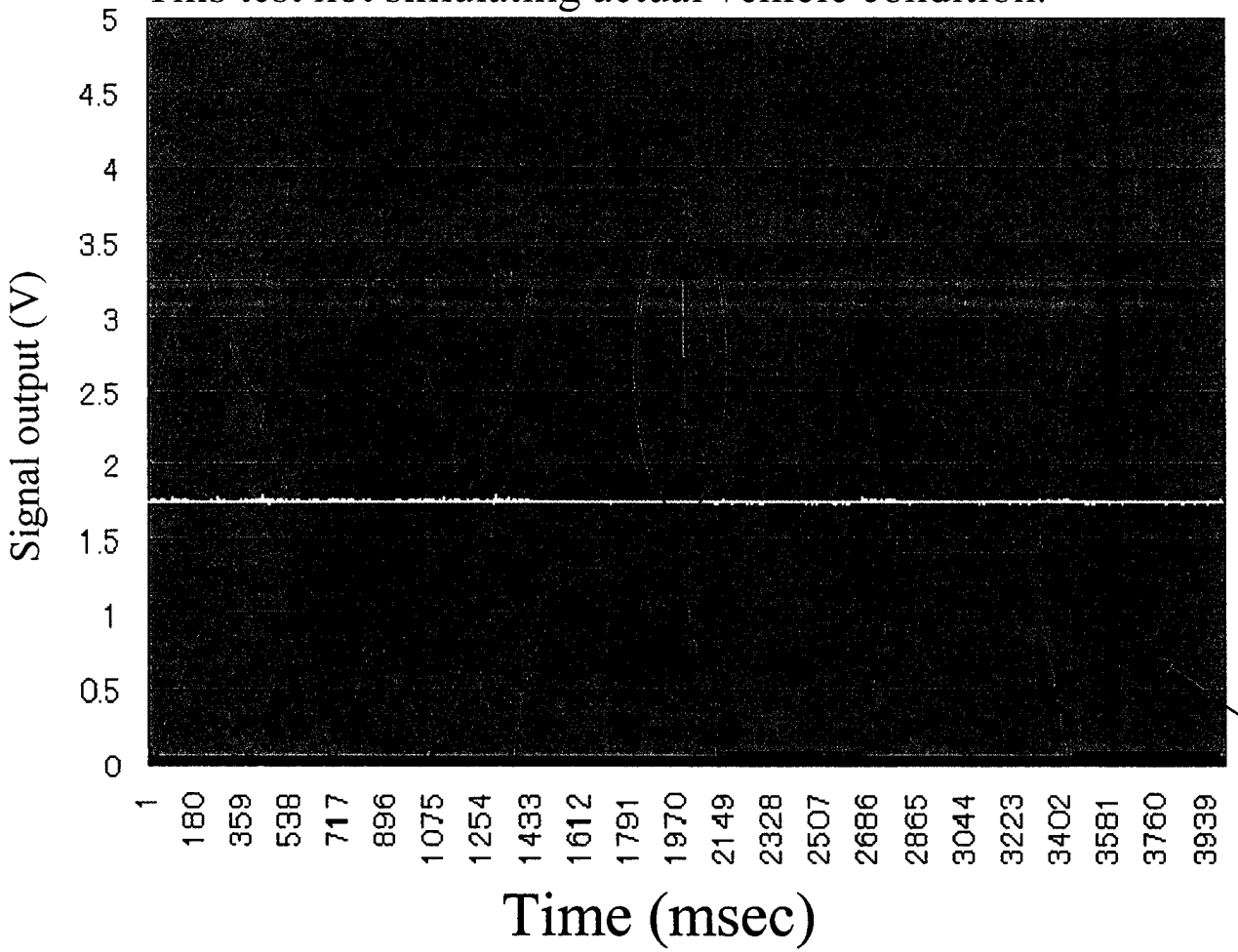
2. Signal noise duplication during sensor wobbling

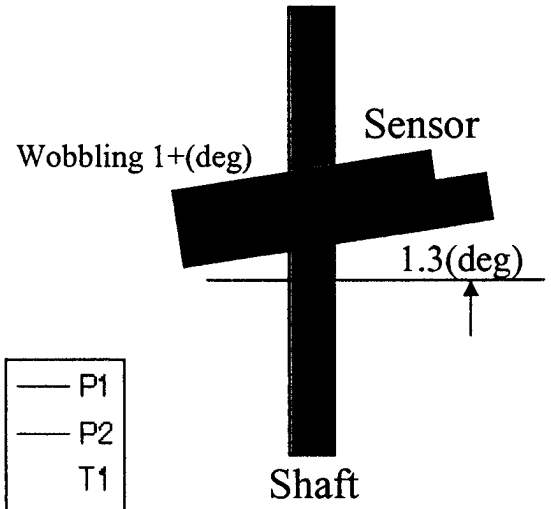
13/May/04 FEC

2-3 Spin test with competitor's sensor. (Fig 10)

Just reference: extreme stress test

This test not simulating actual vehicle condition.





400,000 rotations
@0(deg) tilting (No Noise)

100,000 rotations tilting
@1.3(deg)= wobbling
1+(deg) (Noise produced)

100,000 rotations
@0(deg) tilting (No Noise)

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Conclusion

13/May/2004 Furukawa Electric

1. We found no significant difference in performance between Low-Friction plating and Normal plating.

2. Root cause : Stick slip due to Combination of following items.
   (1) Improper installation alignment of the sensor to EPS column. (not completely seated)
   (2) Less robustness design of sensor compared with the competitor's.
   Competitor : Single function (relative only)
   Furukawa : Delphi required combined design (relative and absolute)

3. Furukawa would like to have joint investigation with Delphi and GM to confirm further details.

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Root Cause Investigation by Furukawa

Conclusion: Wobbling of the sensor in EPS Column

FHGA-04010002 13/May/04 Furukawa Electric Co.,

1: Analysis of Warranty returned sensors

Stand-offs (Stopper) inside Sensor were damaged.

Standoffs of ALL (23/23 pcs) returned sensors were found to be damaged when disassembled at FEC.

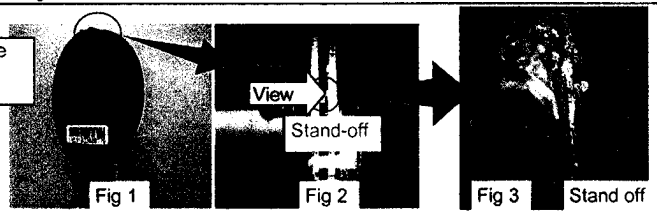


Fig 1 Fig 2 Fig 3

Sensors were not installed according to design.

In all (12/12 pcs) warranty claim columns returned to FEC, sensors were not installed completely to the bottom of the Lower Shaft.

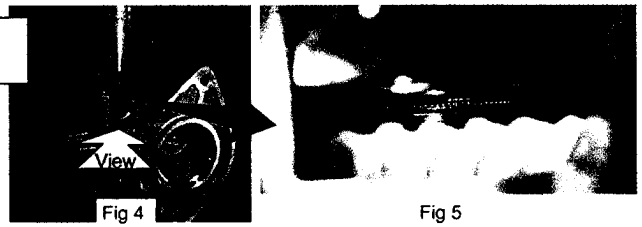
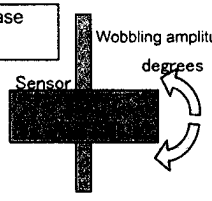


Fig 4 Fig 5

The wobbling amplitude of case was 0.66(deg) on average.

* Returned Sensors (N=4):
The Wobbling amplitude of EPS column returned to FEC was 0.66 degrees on average.



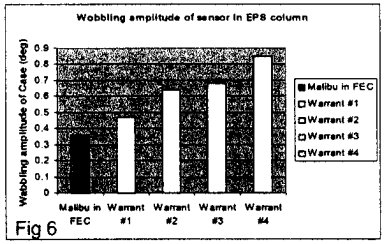


Fig 6

3: Sulfur detected on brushes of Warranty Sensors. (reference)

FEC performed EPMA analysis on the brushes of warranty returned sensors. Sulfur, which can be the cause of contact failures, was detected on warranty sensor brushes as shown in Fig 13. We have doubts that Sulfur is a contributing cause because we detected Sulfur on 3 sensors returned from Milford proving ground. However, we are investigating how the presence of Sulfur affects the reliability of the FEC contacting sensor.

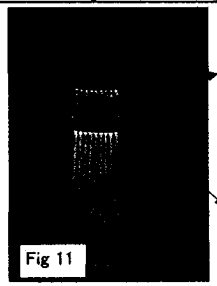


Fig 11

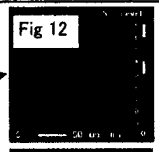


Fig 12 Brand new sensor

Fig 13 Warranty returned sensor
Bright area shows the existence of Sulfur.

2: Signal Noise duplication during Sensor Wobbling

Signal noise was produced when the sensor wobbled in Spin test.

The sensor rotors are rotated at maximum speed of 300 rpm for 100,000 rotations applying wobbling on purpose. The signals are continuously monitored without a low pass filter used in actual vehicles. The trigger level for detecting signal error is 6 times more stringent than the specification of the sensor. The probability of signal noise increases when the wobbling amount increases, as shown in Fig 7, 8. With normal plating, the tendency is the same. Fig 7 shows only the large noise incidents from Fig 8 data.

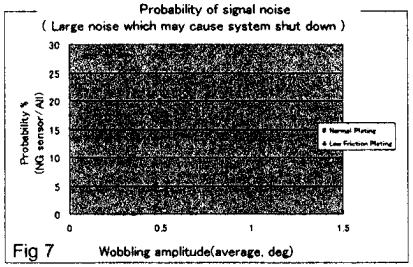


Fig 7

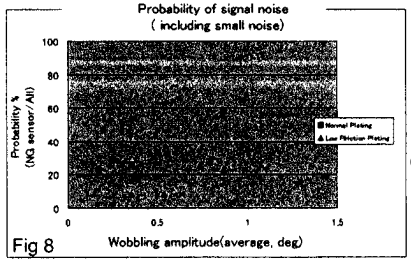
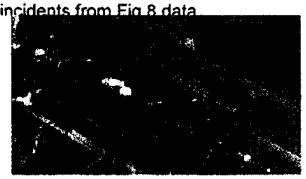


Fig 8

Test stand



When the sensor is wobbling, the wires move side ways, and produce a stick slip motion.

Side ways motion can easily cause the stick slip of all wires resulting in an unstable contacting condition.

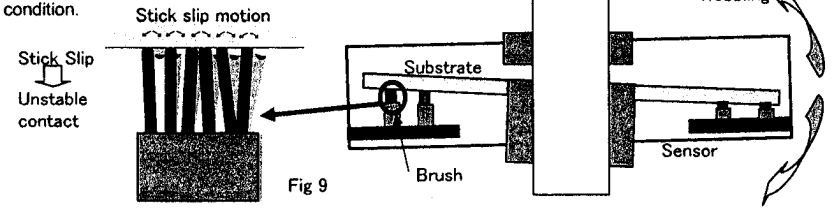


Fig 9

Competitor's sensor also produces signal noise when the brushes slip out of the sliding track. (reference)

This is extreme stress test
This test not is simulating actual vehicle condition.

When we performed Spin test using competitior's sensor at FEC, significant signal noise was detected when the sensor was tilted at 1.3 degrees from the shaft. After changing the tilting angle to 0 degrees the noise disappeared. But the robustness of competitor's sensor is higher than FEC's. Probability of noise cereation may be much lower than FEC's.

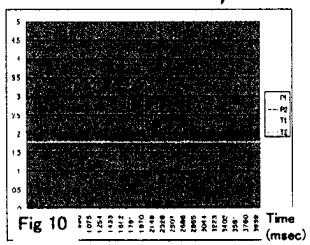


Fig 10